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**F<sub>V</sub> ANTIBODY CONSTRUCT COMPRISING BINDING SITES FOR A CD16  
RECEPTOR AND A CD30 SURFACE PROTEIN**

The present invention relates to F<sub>V</sub> antibody constructs which can induce a regression of Hodgkin's disease, to DNAs coding for such F<sub>V</sub> antibodies and a method of producing the F<sub>V</sub> antibody constructs as well as their use.

Natural antibodies have four variable domains, i.e. two V<sub>H</sub> domains and two V<sub>L</sub> domains. The variable domains serve as binding sites for an antigen, a binding site being formed of a V<sub>H</sub> domain and a V<sub>L</sub> domain. Natural antibodies have two equal binding sites, i.e. they recognize an antigen and are therefore also referred to as being monospecific. Artificial antibodies may also have two different binding sites, i.e. they then recognize two antigens and are correspondingly referred to as being bispecific. An example of such antibodies is an antibody recognizing the FcγIIIA receptor (CD16) of natural killer cells (NK cells) and of the surface protein CD30 of Hodgkin's disease cells. NK cells can be activated by this antibody (bimAbHRS-3/A9) and directed against Hodgkin's disease cells so as to induce a regression of Hodgkin's disease (cf. Hartmann, F et al., Blood 89 (1997), 2042). On the other hand, it turned out that bimAbHRS-3/A9 can only be produced or purified with difficulty. It also turned out that bimAbHRS-3/A9 causes undesired immune responses in many patients.

It is thus the object of the present invention to provide an antibody serving for inducing a regression of Hodgkin's disease by avoiding the above drawbacks.

According to the invention this is achieved by the subject matters defined in the claims.

The present invention is based on Applicant's insights that an F<sub>v</sub> antibody construct comprising binding sites for a CD16 receptor and a CD30 surface protein can induce a regression of Hodgkin's disease, the lysis of the tumor cells being more intense than when bimAbHRS-3/A9 is used. He also found out that such an F<sub>v</sub> antibody construct can be produced in large amounts and with high purity. Furthermore, the F<sub>v</sub> antibody construct distinguishes itself in that it contains no portions which can result in undesired immune responses in patients.

According to the invention Applicant's insights are used to provide an F<sub>v</sub> antibody construct having binding sites for a CD16 receptor and a CD30 surface protein.

The term "F<sub>v</sub> antibody construct" refers to an antibody construct having variable domains but no constant domains. In particular, bindings sites for a CD16 receptor and a CD30 surface protein are available as variable domains.

The expression "binding site" refers to a V<sub>H</sub> domain and a V<sub>L</sub> domain by means of which the F<sub>v</sub> antibody construct may bind to a CD16 receptor and/or a CD30 surface protein.

The term "CD16 receptor" comprises a CD16 receptor of any kind and origin. For example, the CD16 receptor may be derived from NK cells, macrophages or activated monocytes. The CD16 receptor may also be present in wild-type or modified form, the latter form also comprising a fragment of a CD16 receptor to which an antibody directed against a CD16 receptor can bind.

The expression "CD30 receptor" comprises a CD30 receptor of any kind and origin. For example, the CD30 receptor may be derived from Hodgkin's disease cells or Reed-Sternberg cells. The CD30 receptor may also be available in wild-type or modified form, the latter form also comprising a fragment of a CD30 receptor to which an antibody directed against a CD30 receptor can bind.

An F<sub>V</sub> antibody construct according to the invention has one or more binding sites for a CD16 receptor and one or more binding sites for a CD30 surface protein. The F<sub>V</sub> antibody construct preferably has one or two binding sites for a CD16 receptor and one or two binding sites for a CD30 surface protein.

An F<sub>V</sub> antibody construct according to the invention can also be prepared by various methods. For example, an F<sub>V</sub> antibody construct which has a binding site for a CD16 receptor and a binding site for a CD30 surface protein, can be produced e.g. by expressing a first single-chain F<sub>V</sub> antibody construct which has a V<sub>H</sub> domain of an anti-CD16 antibody and a V<sub>L</sub> domain of an anti-CD30 antibody, together with a second single-chain F<sub>V</sub> antibody construct which has a V<sub>L</sub> domain of an anti-CD16 antibody and a V<sub>H</sub> domain of an anti-CD30 antibody, so that both are placed together and the F<sub>V</sub> antibody construct according to the invention is formed. Reference is made to Example 1-3 by way of supplement.

An F<sub>V</sub> antibody construct which has two to four binding sites for a CD16 receptor and two binding sites for a CD30 surface protein, can also be produced e.g. by expressing a single-chain F<sub>V</sub> antibody construct comprising the elements (a) and (b):

- (a) a V<sub>H</sub> domain of an anti-CD16 antibody and a V<sub>L</sub> domain of an anti-CD30 antibody, the domains being joined via a peptide linker 1 which may comprise any amino acids, in particular glycine (G), serine (S) and proline (P), and preferably 0 to 10 amino acids,
- (b) a V<sub>H</sub> domain of an anti-CD30 antibody and a V<sub>L</sub> domain of an anti-CD16 antibody, the domains being joined via the above peptide linkers 1,

the elements (a) and (b) being joined via a peptide linker 2 which may comprise any amino acids, in particular glycine, serine and proline, and preferably 3 to 10 amino acids, and more preferably the amino acid sequence GGPGS. Reference is made to Applicant's patent application 198 19 846.9 by way of supplement.

Another subject matter of the present invention relates to a nucleic acid, in particular a DNA, which codes for an above F<sub>v</sub> antibody construct. Furthermore, expression vectors containing such a DNA also represent a subject matter of the present invention. The preferred expression vector is pKID16-30 of figure 1. It was deposited with DSMZ (*Deutsche Sammlung für Mikroorganismen und Zellen* [German-type collection for micro-organisms and cells]) under DSM 12960 on July 29, 1999. Cells containing an above expression vector are also a subject matter of the present invention.

Another subject matter of the present invention is a kit comprising

- (a) an F<sub>v</sub> antibody construct according to the invention, and/or

- (b) an expression vector according to the invention, as well as
- (c) common auxiliary substances, such as buffers, solvents, carriers, controls and markers.

One or more representatives of the individual components may be present.

The present invention provides an F<sub>V</sub> antibody construct having binding sites for a CD16 receptor and a CD30 surface protein. This F<sub>V</sub> antibody construct can be produced in large amounts and with high purity. Also, it does not contain any portions or fragments which can result in undesired immune responses in patients. The F<sub>V</sub> antibody construct distinguishes itself in particular by activating NK cells and adjusting or orienting them to cells expressing CD30 surface proteins, in particular tumor cells, more preferably Hodgkin's disease cells or Reed-Sternberg cells, so as to lyse these cells. Thus, the present invention is suited to take steps against diseases in which cells expressing CD30 surface proteins play a role. Such diseases are e.g. tumoral diseases, in particular Hodgkin's disease.

**Brief description of the drawings:**

Figure 1 shows the pKID16-30 expression vector according to the invention. It codes for two single-chain F<sub>V</sub> antibody constructs one of which having the V<sub>H</sub> domain of an anti-CD16 antibody and the V<sub>L</sub> domain of an anti-CD30 antibody and the other having the V<sub>H</sub> domain of an anti-CD30 antibody and the V<sub>L</sub> domain of an anti-CD16 antibody. Having expressed the single-chain F<sub>V</sub> antibody constructs, they are

placed together so as to obtain the F<sub>v</sub> antibody construct according to the invention.

Figure 2 shows a FACS analysis of the binding of an F<sub>v</sub> antibody construct according to the invention to CD30<sup>+</sup> L540CY Hodgkin's disease cells and CD16<sup>+</sup> granulocytes. The tumor cells and the granulocytes were incubated with 20 µg of the F<sub>v</sub> antibody construct according to the invention each. The binding of the F<sub>v</sub> antibody construct was determined using the anti-c-myc antibody 9E10 and fluorescein-conjugated goat anti-mouse IgG. The cells were incubated as such with 9E10 and fluorescein-conjugated goat anti-mouse IgG as negative control.

Figur 3 shows the cytolytic activity of NK cells contained in peripheral blood lymphocytes (PBL cells) (effector) as against CD30<sup>+</sup> L540CY Hodgkin's disease cells (target cells) with different effector target cell relationships in a 5 h JAM test. An F<sub>v</sub> antibody construct according to the invention (●) was administered at a concentration of 1 µg/ml. bimAbHRS-3/A9 (▲) was used at a concentration of 4 µg/ml as a control. The F<sub>v</sub> antibody construct without NK cells (○) and NK cells alone (□) were used as negative control.

Figure 4 shows the treatment of SCID mice carrying Hodgkin's disease xenografts with an F<sub>v</sub> antibody construct according to the invention. On day 0, the mice were treated i.v. using 100 µg of an F<sub>v</sub> antibody construct according to the invention together with PBL cells containing NK cells (●) or

without them (○), with 200 µl PBS (\*), with 1 x 10<sup>7</sup> PBL cells (◻) or with a mixture of 100 µg mAb HRS-3 and A9 together with PBL cells (◊). The tumor diameters were measured twice a week, and the tumor volume was calculated using the following formula: volume =  $d^2 \times D \times \pi / 6$ , d being the smaller tumor diameter and D being the larger one.

**Example 1: Construction of the pKID16-30 expression vector according to the invention**

The cDNA of the V<sub>H</sub> and V<sub>L</sub> domains of an anti-CD16 antibody mAb A9 was subjected to PCR. The following primers were used for this purpose:

VH5', 5-CAGCCGGCCATGGCGCAGGTC(G)CAGCTGCAGC(G)AG-3 (NcoI);  
 VH3', 5-CCAGGGGCCAGTGGATAGACAAGCTTGGGTGTTGTTT-3 (HindIII);  
 VL5', 5-AGAGACGCGTACAGGCTGTTGTGACTCAGG-3 (MluI);  
 VL3', 5-GACTGCGGCCGCAGACTTGGGCTGGCC-3 (NotI).

The PCR was carried out as follows: one cycle; 5 min. at 94°C, 3 min. at 58°C, and 2 min. at 72°C, followed by 30 cycles; 80 sec. at 94°C, 80 sec. at 58°C, and 2 min. at 72°C and/or the latter 10 min. in the last cycle. The PCR products were gel-purified and inserted in the pCR-Script SK(+) vector (Stratagene company) for sequencing. For the purpose of expression the V<sub>H</sub> domain was inserted via NcoI/HindIII and the V<sub>L</sub> domain was inserted via MluI/NotI in the pHOG21 vector.

The V<sub>H</sub> and V<sub>L</sub> domains of an anti-CD30-scF<sub>v</sub> fragment were subjected to PCR. The following primers were used for this:

5-ATGACCATGATTACGCCAAGC-3  
 5-AGACAAGCTTGGGTGTTGTTTTGGCTGAGGAGACGG-3 (HindIII);  
 5-GGCGGATATCGAGCTCACTCAGTCTCC-3 (EcoRV)  
 5-TATAGCGGCCGCAGCATCAGCCGTTTGATTTC-3 (NotI).

The  $V_H$  and  $V_L$  domains of the anti-CD30-scFv fragment or the anti-CD16-scFv fragment were inserted in the expression vector pKID so as to obtain the pKID 16-30 expression vector according to the invention. It codes for the single-chain  $F_v$  antibody constructs  $V_H$ , 16- $V_L$  30 and  $V_H$  30- $V_L$  16.

**Example 2: Expression of the  $F_v$  antibody construct according to the invention in bacteria**

*E. coli*-X11 Blue cells (Stratagene, La Jolla, C.A.) which had been transformed with the pKID16-30 expression plasmid, were cultured in 2YT medium using 100  $\mu$ g/ml ampicillin and 100 mM glucose at 37°C overnight. 1:20 dilutions of the overnight cultures were cultured as flask cultures in 2YT medium at 38°C while shaking at 280 rpm. The bacteria were pelleted by 10-minute centrifugation at 1500 g at 20°C with an OD<sub>600</sub> value of 0.8 and resuspended in the same volume of a fresh 2YT medium containing 100  $\mu$ g/ml ampicillin and 0.4 M saccharose. IPTG was added at a final concentration of 0.1 M and the growth was continued at 21°C (20-22°C) for 18-20 h. The  $F_v$  antibody construct was isolated as described by Kipriyanov, S.M. et al., Protein Engineering 10, (1997), 445. Thereafter, it was concentrated by ammonium sulfate precipitation (final concentration: 70 % saturation). The protein precipitate was obtained by centrifugation (30,000 g, 4°C, 45 min.) and dissolved in 10 % of the initial volume from 50 mM Tris-HCl, 1 M NaCl, pH 7.0. An immobilized metal affinity chromatography (IMAC) was carried out as described by Kipriyanov, S.M. et al., J. Immunol. Methods 200, (1997), 69. The purified  $F_v$  antibody construct was dialyzed against a phosphate-buffered common salt solution.



**Example 3: Characterization of the F<sub>v</sub> antibody construct according to the invention**

**(A) Flow cytometry**

In order to detect the binding of an F<sub>v</sub> antibody construct according to the invention to CD16<sup>+</sup> granulocytes and CD30<sup>+</sup> L540CY Hodgkin's disease cells, FACScan (Beckton Dickinson) analysis was carried out. For this purpose,  $1 \times 10^6$  cells were washed twice in icecold PBS-N (PBS, 0.05 % NaN<sub>3</sub>) and incubated on ice with 100  $\mu$ l of the F<sub>v</sub> antibody construct of Example 2 for 45 min. The cells were pelleted at 1200 rpm at 4°C for 5 min. and washed with 2 ml PBS-N. The cells were resuspended in 100  $\mu$ l PBS-N containing 10  $\mu$ g/ml of the 9E10 antibody binding to c-myc (ICI Chemikalien), and incubated on ice for 30 min. The cells were pelleted and washed as described above. Thereafter, the cells were resuspended with fluorescein-labeled goat anti-mouse IgG (Gibco BRL; diluted 1:100 in PBS-N), and incubated on ice for 30 min. After another wash step using PBS-N, the cells were ready for analysis with PBS-N containing 1  $\mu$ g/ml propidium iodide (Sigma). Background fluorescence was determined by incubating the cells with the 9E10 antibody and fluorescein-labeled goat anti-mouse IgG under equal conditions.

It turned out that the F<sub>v</sub> antibody construct according to the invention detects both CD16<sup>+</sup> granulocytes and CD30<sup>+</sup> L540 CY Hodgkin's disease cells and binds to them.

**(B) Cytotoxicity assay**

In order to detect the activity of an F<sub>v</sub> antibody construct according to the invention regarding the activation of NK cells and the lysis of CD30<sup>+</sup> L540CY Hodgkin's disease cells,

a cytotoxicity test was carried out according to the JAM test described by Matzinger, P., J. Immunol. Meth. 145 (1991), 185. DNA fragmentation is evaluated in the cytotoxicity test. Cells were labeled using [ $^3\text{H}$ ] thymidine up to a final concentration of 2.5-5  $\mu\text{Ci}/(\text{ml})$  for 4-6 h. The cells were pelleted, washed once with culture broth and adjusted to  $10^4$  cells/well of a 96-well plate. Having added effector cells (peripheral blood cells containing NK cells ("PBL cells") at various dilutions, the 96-well plate was incubated in a humidified atmosphere with 7.5 %  $\text{CO}_2$  for 4 h. The cells and the medium were sucked onto fiber glass filters. Having washed and dried the filters, they were transferred into plastic bags containing a scintillation liquid and counted using a liquid scintillation counter (LKB). The radioactivity measured refers to intact DNA, since DNA from dead cells is degraded into small fragments which are not retained by the filters. In order to determine the cytotoxicity, *i.e.* the killing of cells, the standard formula for the JAM test was used: % specific killing =  $(S-E)/S \cdot 100$ , with E = experimentally obtained DNA in the presence of effector cells (in cpm) and S = obtained DNA in the absence of effector cells (spontaneously).

It turned out that an  $\text{F}_\text{v}$  antibody construct according to the invention can activate NK cells and lyse  $\text{CD30}^+$  L540CY Hodgkin's disease cells, the lysis being more intense than when bimAbHRS-3/A9 is used.

### **(C) Influence on murine tumors**

$\text{CD30}^+$  L540CY Hodgkin's lymphomas were established in SCID mice as described by Hombach, A. *et al.*, Int. J. Cancer 55, (1993), 830; Renner, C. *et al.*, J. Hematotherapy 4, (1995), 447. To this end,  $1.5 \times 10^7$  tumor cells in 200  $\mu\text{l}$  PBS were

injected subcutaneously into the right side of the mice. The tumor development, *i.e.* the diameter of the tumor, was determined twice a week. Mice suffering from tumors of 4-6 mm in diameter were divided into various groups and were given an F<sub>v</sub> antibody construct according to the invention in 200 µl PBS together with peripheral blood lymphocytes containing NK cells (PBL cells). The tumor volume and its development were determined (*cf.* legend of figure 4).

It turned out that an F<sub>v</sub> antibody construct according to the invention can activate NK cells both *in vitro* and *in vivo*, lysing CD30<sup>+</sup> L540CY Hodgkin's disease cells.